GROWTH IN SEEDLINGS OF PHASEOLUS VULGARIS IN RELATION TO RELATIVE HUMIDITY AND TEMPERATURE

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Cecil Frederick Patterson

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BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy.

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I. ACKNOWLEDGMENT.

The work here reported was performed in the Laboratory of Plant Physiology, University of Illinois, under the direction of Prof. C. F. Hottes. The writer feels greatly indebted to Professor Hottes for suggesting the problem and for his ever-ready and continuous assistance in constructing and arranging the apparatus. His suggestions on methods of experimentation and on working up the data are fully appreciated, and only through his efforts and his encouragement, during the course of the investigation, has the material here presented been made available.

II. INTRODUCTION.

It is an undisputed fact that environmental conditions play an important rôle in determining the rate of growth in plants. Agriculturists, horticulturists, and others interested in the growing of plants have observed that certain conditions of environment are favorable to growth, while other conditions are unfavorable and retard this fundamental life process. During one season, plants of a given species thrive and produce vigorous growth, while during the season following, on the same soil and under similar cultural conditions, the corresponding growth rate suffers a marked decrease. In a like manner, growth during one period in the growing season may be more rapid by night than by day, while during another period, in the same season, the reverse may be true.

As to what factor or factors are responsible for the differences in the responses of plants to the physical environment little is known. In the literature on plant physiology, some of the differences in plant response have been attributed to variations in definite environmental factors with little or no experimental evidence to substantiate the conclusions drawn. Plant physiologists, plant ecologists and others, in studying growth, have noted differences in the behavior of plants growing under different sets of conditions and, in many cases, have ascribed the differences in growth to a variation in one factor

when the cause might reasonably be attributed to a variation in several factors. In such cases it was not realized that the changing of one environmental factor resulted in a changing of two or more factors. For instance, Reinke ('76), in early studies on plant growth, observed that a change from light to darkness was usually accompanied by an increase in the relative humidity. The conclusion of Brefeld ('77) that the formation of the pileus in Coprinus depended upon the presence of light was found to be in error. Lakon ('07) showed that excluding the light from the vessel in which the fungus was growing changed the temperature and the relative humidity of the atmosphere surrounding the fungus. Experience has shown that, in nature, light, temperature and relative humidity are closely interrelated and that the condition of one is dependent, in a marked degree, upon the condition of the other two. As the light decreases in intensity the temperature falls and reaches a minimum during the hours of darkness. With this fall in temperature an increase in the relative humidity follows. On the return of light the temperature rises and a fall in the relative humidity results. To these rapid and often wide changes little attention has been paid by many workers in the field of plant physiology.

From a study of the plant environmental complex, as a whole, it may be seen that, in growth studies, every factor must receive due consideration. Jost ('07) recognized that the daily periodicity in relative humidity, in temperature and in light, occurring in nature, act unequally and often antagonistically

upon the growth processes. The same authority acknowledged that it was impossible to interpret growth responses as affected by three variables combined. High temperatures, during the day, may retard growth and during the night, when the temperature drops to near the optimum, the growth rate may increase. Likewise, conditions may exist where the converse is true. Still more complex is the problem when the relationship of soil temperature to these factors and to growth is considered. Free ('11) maintains, "As a part of the surrounding temperature the temperature of the soil is scarcely less important than that of the air". On the other hand, Godlewski has shown that a drop in the soil temperature from 20.7 C. to 5.5 C. results in an insignificant decrease in the growth rate of the shoot. MacDougal ('03) has shown that the soil temperature, at the average depth for roots of herbaceous plants, reaches a maximum between 8 and 11 o'clock in the evening and a minimum between 8 and 10 o'clock in the forenoon. From this it is evident that when the atmospheric temperature is falling, during the early hours of the night, the relative humidity and the soil temperatures are rising, and when the atmospheric temperature is rising, in the early part of the day, the relative humidity and the soil temperature are falling.

In order to avoid making the errors so common in much of the experimental work in plant physiology, it is necessary to carry out experiments under conditions that are absolutely under the control of the operator. DeCandolle ('05) recognized the

importance of controlled conditions in a study of plant growth, and in an address, cited by Abbe ('05), emphasized the need for plant houses in which the various environmental factors could be controlled and changed at will. This need received the endorsement of Abbe ('05), who recognized the limitations of correlating field observations on plant growth with climatic data. In a recent work, Livingston ('17) has sounded a note of warning to the investigator and has drawn attention to the fact that, for solving the fundamental problems in growth, an environmental control apparatus is indispensable.

Only recently has the dream of DeCandolle been realized. For some years, chambers in which the light and atmospheric temperature factors could be maintained constant or changed as desired have been in existence; but where relative humidity plays a part in determining the growth response, the usefulness of such chambers is limited. In the plant chambers recently devised by Hottes ('21), the humidity factor also is under control. These chambers, which are sufficiently large to accomodate higher plants throughout their entire growing period, are so arranged that the light, temperature and moisture factors are under perfect control of the investigator.

From a study of the methods of experimentation adopted by the various investigators in this field, it may be seen that in many cases the conclusions reached are unwarranted. The increase in the rate of elongation in shoots of sunflower during darkness, obtained by Reinke ('76), may have been due to an in-

crease in relative humidity, as he maintains; but since the environmental factors were not under control, temperature may have played a part in bringing about this change in the growth rate. The agreement of the growth curve in Cucurbitaceous fruits with the changes in relative humidity, observed by Clark ('78), Darwin ('93) and Anderson ('94), may have been due to conditions of relative humidity alone. Since, however, the periods of high relative humidity, recorded by them, occurred when the sun was obscured and the periods of low relative humidity when the sun was shining, temperature may have been a very important factor influencing the rate of enlargement. The increase in the growth rate in Dendrocalamus during the night over that during the day at Peradeniya and Anuradhapura, recorded by Smith ('06), suggests that the lower temperatures, obtaining during the hours of darkness, were more favorable to growth than were the higher ones characterizing the day, and that this increase was not the effect exclusively of an increase in the relative humidity. The increases in the growth rate in plants during darkness, observed by Sachs ('74), indicate that factors other than light may have been responsible, in part, for this phenomenon.

Owing to the absence of proper means of controlling the environmental factors in previous investigations, little is known absolutely concerning the effect of relative humidity on growth in plant shoots. The problems in growth cannot be solved from observations on plants growing under fluctuating conditions of environment. In order to be able to draw correct

conclusions, the data must be obtained from plants growing under conditions where each individual factor of the environmental complex may be maintained constant or varied at the wish of the experimenter. The variations in the intensity and in the quality of light, occurring in nature, must be eliminated; the fluctuations in the atmospheric temperature and in the relative humidity, characteristic of most climates, must be overcome; the soil temperature and the soil moisture supply must be under the control of the investigator, and the availability of the food materials, during any series of experiments, must be maintained constant before a solution to the factors influencing growth can be given.

With an apparatus for controlling both root and shoot conditions available, the present study was undertaken. This study was designed to assist in clearing up the divergent views held in respect to growth in relation to relative humidity and temperature. The problem is large and the working of it out in detail will require a life time. In the present work only a beginning has been made, and the extent of the investigation was limited to a study of growth in seedlings subjected to few of the many possible combinations of environmental conditions. The major part of the investigation was carried out on etiolated seedlings. The differences in their response to humid and to dry atmospheres may seem insignificant, but it should be remembered that a beginning must be made, and the logical point of attack is in seedlings not exposed to the influences of light. In the minor part of the work, which consisted in a study of

illuminated seedlings in the presence of high and low relative humidities, less significant results were obtained. Though very limited in extent, the latter have a direct application to growth under conditions occurring in nature.

III. REVIEW OF LITERATURE.

In the literature on plant physiology, much may be found dealing with the influence of temperature upon growth in [redacted] plants. The studies of Sachs ('60, '74, '92), Koeppen ('75), Reinke ('76), Askenasy ('90), Godlewski ('91, '93), Ward ('95), True ('95), Balls ('08), Lehenbauer ('14) and others have given to us a knowledge of the basic laws governing growth in relation to temperature. The humidity relations, on the other hand, have been, in a large degree, overlooked. It is true that authors have made reference to high relative humidity as a factor increasing the growth rate, but little absolute experimental evidence is available. The growth rate has been changed with a change in the relative humidity, but in many cases, it is evident that the relative humidity was very imperfectly controlled and that the humidity changes were accompanied by changes in other environmental factors.

One of the earliest attempts to determine the effect of relative humidity on growth, recorded in literature, is that of Reinke ('76). This author compared the respective growth rates of potted plants of sunflower (Helianthus annuus) placed near a window,

one under a bell jar and one in the free circulating atmosphere of the laboratory. He observed that the growth rate in the plant under the bell jar was much greater than that of the plant in the free air. This increase in the growth rate exhibited by the plant under the bell jar was due, he believed, to the higher relative humidity obtaining in the atmosphere surrounding the plant. Where the humidity was not controlled, growth during darkness exceeded that during light. Later, he was able to show that under conditions of constant relative humidity growth in plants exposed to light was more rapid than that in the same plants maintained in darkness. He explains this discrepancy on a basis of a higher relative humidity obtaining in the absence of light. In further investigations, he found that growth in thickness in stems of Datura was proportional to the relative humidity and that Datura leaves exhibit a more rapid growth by night than by day. This latter observation can be accounted for, he maintains, by the existence of a higher relative humidity during the hours of darkness than during the hours of light.

The researches of Sorauer ('80) on summer barley show that with an increase in the relative humidity an increase in the rate of elongation results. The plants grown in a dry atmosphere, however, were stockier and possessed greater fresh and dry weights than did those grown in a humid atmosphere. Later, the same author reports results obtained from subjecting

plants of Pyrus communis, Vitis vinifera, Ailanthus glandulosus and Lupinus luteus to dry and to humid atmospheres. His observations show that in plants of some species a humid atmosphere accelerates growth, while in plants of other species growth takes place more rapidly in the presence of a dry atmosphere. In Lupinus, the plants grown in a humid atmosphere possessed longer stems and greater fresh weights than did the plants grown in a dry atmosphere. The plants grown in a dry atmosphere, however, possessed the greater dry weight.

Reinitzer ('81) demonstrated that atmospheric humidity plays a significant rôle in determining the rate of elongation in plant shoots. By subjecting shoots of Evonymus japonicus, Tradescantia viridis and Nerium oleander to dry and to humid atmospheres, he observed that the rate of elongation in the humid atmosphere was from two to four times as rapid as that in the dry atmosphere.

In pea seedlings Vesque and Viet ('81) observed a great difference between the growth rates in dry and moist atmospheres, respectively. Without exception, elongation in roots took place more rapidly in a humid atmosphere than in a dry atmosphere. In shoots, this was true in the case of one plant only. Taking the average values, elongation in shoots proceeded more rapidly in a dry atmosphere than in a humid atmosphere, while in roots the converse was true.

Hellriegel ('83) demonstrated that under favorable conditions of soil moisture a low relative humidity may be not

less favorable to growth than a high relative humidity. Plants of barley, grown in a soil whose moisture content varied from 20 to 60 per cent saturation, made as rapid growth in the presence of a dry as in the presence of a moist atmosphere. He states "Diese Änderung der Verdunstungsgrösse übt aber keinen Einfluss auf die physiologischen Funktionen der Pflanzen, auf ihre Produktion und Gesamtentwickelung aus, so lange die Bodenfeuchtigkeit innerhalb normaler und günstiger Grenzen erhalten wird".

The researches of Brenner ('00) on Sempervivum assimile and on Sedum dasyphyllum, indicate that a high relative humidity brings about an excessive elongation in plant shoots. According to this author, plants grown under very humid conditions resemble, in respect to height, those grown in the absence of light. In Sedum, he observed that at distances of 1.5 meters and 5.0 meters from a window and in the free air seedlings made, in a period of 14 days, a growth of from 3 to 6 millimeters and from 6 to 14 millimeters, respectively. At the same distances and during a period of similar length, but under a bell-jar, they made a growth of from 5 to 8 millimeters and of from 10 to 20 millimeters, respectively.

Unlike the results of Brenner are those obtained by Schaible ('01). This investigator exposed potted plants of the bean (Phaseolus vulgaris) and plants of the same species, growing in nutrient solutions, to a dry atmosphere and compared the growth rate in these plants with the growth rate of similar

plants growing in an atmosphere charged with moisture. In one series the atmospheric pressure remained normal, while in another it was reduced to one-fourth normal. Under both conditions of atmospheric pressure, the growth rate was more rapid (and the leaves larger) in the plants grown in the drier atmosphere. He states, "Nach diesen Resultaten hätte die Luftfeuchtigkeit keinen Einfluss gehabt".

On a basis of dry weight, Tschaplowitz ('86) found that seedlings of Pisum sativum growing in a dry atmosphere exhibited a growth rate unlike that of seedlings of the same species growing in a humid atmosphere. He states, "Wie Zahlen ergeben beträgt das Gewicht der absolut trocknen Pflanzensubstanz der oberirdischen Organe der in den Häusern mit der höhern Dunstsättigung (63 und 47% der relativen Feuchtigkeit) gewachsenen Pflänzchen bedeutend, nahezu 14%, mehr, als das der betreffenden Organe der in den trockneren Vegetationsräumen (mit 46 und 39% der relativen Feuchtigkeit) erzogenen jungen Erbsenpflanzen".

In plants of Phaseolus multiflorus, Godlewski ('91) observed that an abrupt decrease in the growth rate resulted when the plants were changed suddenly from an atmosphere possessing a relative humidity of 64 per cent to one possessing a relative humidity of 38 per cent. This increase in the rate of elongation, however, persisted for a short time only, and the growth rate soon assumed its former value. On increasing the relative humidity from 38 per cent to 87 per cent, a sudden

increase in the growth rate resulted, but this increase was of short duration. After two hours the growth rate in the higher relative humidity was approximately equal to that in the lower relative humidity. He believed that these changes in the growth rate were due to purely physical causes and that they could be explained on a basis of turgor relations. He says, however, "Die epikotylen Glieder der Pflanzen, welche in beständig feucht gehaltener Atmosphäre verweilen, wachsen überhaupt bedeutend schneller und erreichen eine bedeutend grössere finale Länge als die der Pflanzen welche unter sonst ähnlichen Bedingungen in einer trockenen Atmosphäre gezogen werden".

The researches of Clark ('78), Anderson ('94) and Darwin ('93) give support to the conclusions reached by Godlewski. Their investigations show that relative humidity is an important factor in determining the rate of development in fruits of Cucurbita. They have demonstrated that, at times, the rate of enlargement increases or decreases as the relative humidity becomes higher or lower. Clark, in studying the expansive power of a developing fruit of this genus, observed that the pressure was greatest during the early hours of the morning. This, he believed, was due to the presence of a high relative humidity during those hours. Anderson and Darwin made careful hourly weighings of developing fruits and correlated the hourly increments with the conditions of temperature and relative humidity for the corresponding period. Their curves for weight increase follow , in a general way, the curves for

relative humidity. At times this correspondence was perfect. At other times, however, the data suggest that some factor or factors, other than relative humidity, were operating in limiting growth.

An attempt to study growth in relation to atmospheric humidity, in a systematic way, was that of Wollny ('98). His researches in this connection were confined to plants of barley, vetch, lucerne, flax and potato. In general, an increase in the relative humidity brought about an increase in the rate of stem elongation and an increase in the production of plant substance, both fresh and dry.

One of the most extensive investigations on growth in plants, in relation to relative humidity, was carried out by Eberhardt ('03, '04). Plants of many species, including Lupinus albus, Mimosa pudica, Phaseolus vulgaris, Faba vulgaris, Coleus blumei, Ricinus communis and others, were subjected to three different conditions of relative humidity, namely, "Humid", "Normal", and "Dry". The plants maintained in the "Humid" atmosphere consistently made greater growth increments than did those maintained in either a "Normal" or in a "Dry" atmosphere. Likewise, with but one exception, did the plants maintained in a "Normal" atmosphere make greater elongation increments than those maintained in a "Dry" atmosphere.

Similar to the observations of Clark ('78), Anderson ('94) and Darwin ('93) were those of Lock ('04) and Smith ('06).

Smith observed that the growth curve in plants of Dendrocalamus giganteus followed closely the curve for relative humidity during the day at Hakgala and during the day and part of the night at Peradeniya and Anuradhapura. In shoots of Capparis, Stifftia and Eranthemum cinnabarinum the growth rate during the day showed a close correspondence with the relative humidity. Measurements of fruits of Artocarpus integrifolia, taken twice daily, morning and evening, indicate a much higher rate of enlargement during the night than during the day. This, he believed, was due to the presence of a higher relative humidity during the hours of darkness. Lock's observations on Dendrocalamus giganteus, Gigantochloa aspera and Bambusa spinosa were similar to those of Smith. Rate of elongation in shoots of these species, was found to follow closely the fluctuations in the amount of moisture present in the atmosphere.

IV. MATERIALS AND METHODS.

The experimental work upon which this paper is based was carried out on seedlings of the common bean (Phaseolus vulgaris) during the winter months of the years 1920 - 1921. Two adjoining sections of a glass house, in which the heating was under thermostatic control, were appropriated for the purpose of carrying on the investigation. Through a system of ventilation in combination with steam heating, the room temperature was maintained easily within the desired range. The excess light,

on sunny days, was excluded by a coating of green paint applied to the innér surface of the roof, and where necessary the plant chambers were protected by light shades.

1. Apparatus.

The varíous forms of apparatus used by previous investigators in attacking this problem have been of a very imperfect type, and the conditions as stated in their reports are, at the best, only approximately correct. Brenner ('00), Eberhardt ('03, '04), Hellriegel ('83), Reinitzer ('81), Reinke ('76), Schaible ('01), Sorauer ('80) and Vesque and Viet ('81) employed bell-jars, while Godlewski ('91), Wollny ('98) and Bovie ('10) employed chambers in which to grow the plants during the period of observation. The atmosphere, in the bell-jars or in the chambers, was maintained either dry or wet by passing the air, as it entered the enclosed areas, over sulphuric acid or calcium chloride, or through water. To further assist in removing the moisture, Sorauer placed open dishes containing sulphuric acid under the bell-jars, and Schaible relied on this method entirely. A few workers have given the actual values expressing the relative humidity obtaining at the time; while others have merely stated that the atmosphere, in which the plants were growing, was dry or moist. In no case, among the investigations cited, was the relative humidity under automatic control.

Since it was desired, during some of the present

experiments, to maintain the temperature of the root at one point and that of the shoot at another, it was necessary to employ an apparatus by which the temperature of the root could be controlled independently of that of the shoot. Preliminary experiments showed that this could well be done by utilizing a constant temperature water-bath, in maintaining the temperature of the root, and a combined temperature and humidity chamber in the control of the environmental factors of the shoot.

Water-baths. The water-baths used in maintaining the root temperatures consisted of galvanized iron tanks, 20 inches in width, 7 inches in depth and from 3 to 7 feet in length, filled with water to the desired level. Heating of the water was effected by electric heaters, two in each tank, under the control of a thermo-regulator. The temperature of the water was maintained uniform throughout by a system of aeration.

Covering each bath was a sheet of an asbestos compound, known commercially as "Transite". In each sheet, openings were made for the accomodation of the plant shoots and for the lead tubing which conducted the air to the baths for purposes of agitation. In one of the sheets covering each tank, two additional openings were drilled, one for the thermo-regulator, and the other for a cork supporting a thermometer. The openings for the plant shoots were nine in number and measured one and one-fourth inches in diameter. These openings were arranged in the form of a square, with a distance of four and one-half inches from centre to centre.

Plant chambers and air-conditioning apparatus. The plant chambers and the air-conditioning apparatus, employed for controlling the environment of the plant shoots, were essentially the same as those described in detail by Hottes ('21). During these experiments, however, the walls and the door of the chambers were rendered opaque by a covering of heavy paper boards.

Since a means for cooling the atmosphere in the plant chambers was not provided, it was necessary to take special precautions that the temperature of the air in the room did not exceed the temperature of the air in the plant chambers. The temperature of the rooms was kept down by adjusting the thermo-regulator to give low heat and by ventilation on sunny days, when the air temperature in the house was likely to exceed the maximum desired in the plant chambers.

The apparatus, arranged as indicated, worked admirably well and gave highly satisfactory results. The thermo-regulators and humido-regulators proved very sensitive to heat and moisture, respectively. With these instruments properly adjusted, the atmospheric conditions in the plant chambers were maintained constant to a marked degree. In respect to temperature, the variation from the mean was kept at a value less than .5°C. Records, given by a humidograph, show that the humido-regulator is capable of maintaining a relative humidity with a fluctuation of less than 2 per cent. To avoid making unnecessary claims,

the variation, during this investigation, may be put at a value not to exceed 5 per cent - two and one-half per cent in either direction from the mean. A variation of 5 per cent in the relative humidity is not excessive and, within the limits of these experiments, is as little as could be desired.

2. Preparation of Seedlings.

As previously stated, seedlings of the common bean served as plant materials for experimentation. Seedlings of this species were chosen, owing to the ease with which they can be grown and to their great adaptability to laboratory methods. The seeds were of the Red Valentine variety and were obtained from the Burpee Seed Company.

To insure seedlings of uniform vigor, the researches of Blanchard ('10), Bolley ('01), Clark ('04), Cobb ('03), Cummings ('14), Desprez ('95), Fruwith ('17), Grenfell ('01), Haberlandt ('66), Hicks and Dabney ('96), Kiesselbach ('17), Love ('12), Lyon ('05), Miller and Pammel ('01), Montgomery ('08, '12), Sanborn ('92), Shamel ('05), Shaw ('06), Snyder ('05), Soul and Vanatter ('01, '03), Walls ('05), Webber and Boykin ('07), Williams ('03, '05), Wollny ('77, '87) and others (Kidd and West, '18, '19) show the necessity for employing seeds of uniform size. Though the investigations of Middleton ('99) indicate that, in the bean, size of seed has little influence on the resulting plants, the evidence appears to be in favor of the conclusions reached by the former mentioned investigators. Accordingly, the sample of seed, taken at random from a large

supply, was divided into three grades, on a basis of length, by employing a measuring caliper. The first grade included seeds more than 17 millimeters in length; the second those between 13 and 17 millimeters in length; and the third, all those below 13 millimeters in length. For the present study, seeds belonging to the second group were chosen.

In order to determine the relation between reserve (food supply) and growth, under the various conditions of moisture and temperature employed, each bean was weighed individually and its weight recorded to the second decimal place in grams. The beans were germinated at room temperature, in moist sand, in a germinating pan. Upon the radicles reaching a length of from 2 to 3 centimeters, the seedlings possessing radicles showing a small departure from the mean, in respect to length, were transferred to one-quart Mason jars containing the desired culture medium.

As a medium a white silica sand, brought to the desired moisture content by the addition of water from the University wells, was employed. The sand is almost a pure silica, and the water is in itself a well balanced nutrient solution, as shown by the following analysis, furnished by the Illinois State Water Survey ('15):

Mineral salts	Parts per million	Mineral salts	Parts per million
KNO_3	2.3	$MgCO_3$	105.3
KCl	.8	$CaCO_3$	144.8
K_2SO_4	2.0	$FeCO_3$	4.4
K_2CO_3	6.4	Al_2O_3	.6
Na_2CO_3	81.7	SiO_2	15.8
$(NH_4)_2CO_3$	7.5	Bases	3.4
		Total	375.0

To overcome the difficulty experienced by Briggs and Shantz ('13), Kiesselbach ('15), Montgomery ('12), Livingston ('18), Brenchley ('20) and others in maintaining a medium uniform throughout, in respect to moisture, the sand was brought up to the desired moisture content before putting it in the jars and undue evaporation prevented during the development of the seedlings. The respective moisture contents were obtained by mixing together, in a large bowl, a known weight of dry sand and the correct amount of water. The weight of water required in a given case was determined from the value representing the water holding capacity of the sand, as ascertained by a modification of the Hilgard method (Hilgard, '19). Preliminary experiments showed that, with ample precautions, the loss of water from the sand in the jars during the growing period of the seedlings did not exceed 4 per cent of the sand's total water holding capacity. To offset this loss, the moisture content of the sand, at the time of mixing, was made to exceed the stated value for each series of experiments by from 1 to 2 per cent. This treatment provided a sand with an average moisture content, throughout the period of experimentation, equal to, approximately, the values given in the tables. For instance, in the series run in a soil moisture of 20 per cent saturation and in an atmospheric relative humidity of 30 per cent, the moisture content of the sand, at the time of mixing, was made up to 22 per cent. At the close of the experiment this value was found to be approximately 18 per cent. The average for the period, therefore, was 20 per cent.

To secure uniform compactness in the sand, the jars were filled loosely with the moistened sand and were allowed to drop a set distance on a padded board a definite number of times. After this operation the jars were refilled and, with a slight pressure of the hand, the level of the sand brought to the desired distance below the top. The germinated seeds were set one in each jar, at uniform depths below the surface of the medium. A metal cover, with a small perforation to permit exchange of gases, was placed over each jar. The cultures, thus prepared, were enclosed between two circular pans. The cultures were set in one pan, which contained a small amount of water, and the other pan was inverted to form an enclosure. The water in the lower pan was provided to increase the atmospheric humidity surrounding the cultures, in order to prevent excessive evaporation from the sand in the jars. When the cotyledons appeared above the surface of the sand, the small metal covers were removed from the jars, but the cultures were retained within the pan enclosure until ready for transference to the water-bath. In all cases, twice the required number of seedlings were prepared, in order that those exhibiting malformations and that those showing marked departures from the average, in respect to growth rate, might be eliminated.

Upon the seedlings reaching a height of about 4 centimeters, the required number for experimentation was selected, taking those that showed uniformity in height, and prepared for the baths. To the top of each jar was secured a metal

secured by paper clips to a metal strip supported by the wire upright. The seedling was held in contact with the combined scale and support by a small rubber band, sufficiently large to bring only very slight pressure to bear on the shoot. As a precautionary measure against the stimulation of growth, through the agency of contact, the rubber band was placed well below the growing zone.

With this arrangement the heights of the seedlings were read with ease. During the early stages of growth, the readings were obtained through the small openings in the base of the chamber, provided by the doors in the condulet covers. In the later stages of elongation, the readings were obtained through a large glass door, with which each chamber was provided.

After the transference of the cultures to the baths, a period of from 2 to 6 hours elapsed before the first readings were obtained. This was permitted, in order that the seedlings might become accomodated to their new environment. Readings on shoot elongation were obtained twice daily, with a period of 12 hours between readings, and the increments in the hypocotyls and in each internode were recorded separately. At about three-hour intervals, from 7 A.M. to 10 P.M. readings on temperature and on relative humidity were obtained. In this way a close check was kept on the behavior of the thermo-regulator and the humido-regulator. Occasionally an instrument failed to respond.

coger provided with a short bzass tube, centrally located and of sufficient size to permit the passage of the cotyledons and bent hypocotyls. After putting the cover in place, the opening in the tube surrounding the shoot was sealed with plastic clay. The cultures were then labelled and the weight of each jar and its contents was recorded.

At this stage the cultures were in readiness for transference to the water-baths. These baths were situated, as already indicated, below the plant chambers. To permit this transfer, the plant chamber, with its base, was elevated by rope and pulleys, and the sheet of "Transite", which served as a cover for the tank and as floor for the chamber, was removed. The cultures were then put in position, nine below each chamber. The water of the bath was brought to a level of about one inch below the top of the jars, and the sheet of "Transite" replaced. To prevent the entrance of moisture to the plant chamber from the bath below, the joints were sealed with plastic clay. After replacing the chamber and its base, the growth measuring scale and the supports for the seedlings were put in place.

The support for each seedling consisted of a heavy iron washer, to which was riveted an upright of No. 9 galvanized wire. In addition to offering support for the seedlings, these uprights served to support a millimeter scale, from which the height of the seedlings was read directly. The scale consisted of a narrow section of millimeter cross-section paper, which was

In such cases the data obtainedwere discarded and the experiment was repeated. Observations on each lot of seedlings were continued until the shoots ceased elongating.

After elongation in the shoots came to an end, the cultures were removed from the baths and weighed. The seedlings were then removed from the jars, and care was taken to secure the entire root system of each plant. The particles of sand, clinging to the roots, were removed by washing in water. Before weighing, the excess water adhering to the roots was removed by the aid of dry cloths. Immediately following this washing and drying, the fresh weight of each root and shoot was determined and recorded separately. After drying for 24 hours at a temperature of 30°C., these products were transferred to a high temperature oven (95°C.) and there dried to constant weight. With the dry weight determined, the securing of data was completed.

V. OUTLINE OF EXPERIMENTS.

For convenience, the experiments are treated under two sections:

1. Growth of seedlings in continuous darkness.
2. Growth of seedlings in darkness alternating with light.

As already stated, the major part of the investigation was carried out on non-illuminated seedlings. These seedlings

were grown under different conditions of temperature, relative humidity and soil moisture. The conditions obtaining at any one time, however, were maintained constant during the series. Lack of time prevented the using of more than one root temperature, but two shoot temperatures, three relative humidities and three soil moistures were employed. The root temperature, in all experiments, was maintained at 25 C. The other environmental conditions were changed, when desired, giving the following combinations:

Shoot temperature (C.)	Soil moisture (per cent saturation)	Relative humidity (per cent)		
20	5	30	60	90
	20	30	60	90
	60	30	60	90
30	5	30	60	90
	20	30	60	90
	60	30	60	90

The seedlings, included in the experimental work of Part II, were illuminated from 7 A.M. to 7 P.M. Illumination was provided by light from the natural source, entering the plant chamber through a glass top. This was aided by the light from a Ray No. 90 Mogul Projector, furnished with a 125 Watt tungsten bulb. This projector was located 12 inches above the chamber. Under this condition of illumination, a root temperature of 25 C. and a shoot temperature of 30 C. were employed. Pure silica sand, saturated to the extent of 20 per cent, served as a medium, and a relative humidity of 30 per cent was compared, in its effect upon growth, with a relative humidity of 90 per cent.

Seedlings growing in three chambers were simultaneously subjected to a given set of the environmental conditions already named. Since each chamber accommodated nine seedlings, the data on growth, under a given set of conditions, were obtained from 27 seedlings grown in separate jars. At times, however, some of the individuals exhibited growth rates that departed markedly from the normal. Askenasy ('90), True ('95), Lehenbauer ('14) and others discarded such plants and based their conclusions on the data gathered from those individuals exhibiting a normal growth rate. This procedure appears legitimate and in the present work was adopted. In such cases, the number of individuals for a given experiment was reduced. In no case, however, was the number less than 23.

VI. PRESENTATION OF DATA.

Since upwards of 500 seedlings were studied individually, it is evident that the detailed data for each seedling cannot be given in a paper of this length. Even if it were possible to present all of the figures, it seems inadvisable to burden the reader with a mass of detail, especially when the data can be condensed and presented in a form that will show at a glance the relative values of different treatments. In the case at hand, the data has been much condensed, but the aim has been to present as much as is necessary for a clear and correct interpretation of the results.

For each character studied, the mean value and its probable error were determined. The mean weight of the seeds was determined from the values obtained before the seeds were placed in the germinating pan. The mean weights of the shoots, both fresh and dry, were obtained from the values secured at the close of each individual experiment. The average 12-hour increment of elongation for each individual was determined from the value representing the total increment made during the period of observation. From these 12-hour increments the means were determined. The standard deviations, the coefficients of variability and their probable errors were obtained in the usual manner (Davanport, '14).

1. Growth of Seedlings in Continuous Darkness.

In Tables I and II are presented the data showing the rates of elongation in shoots maintained at temperatures of 20°C. and 30°C., respectively. From inspection of the data in these tables, it may be observed that the differences in the increments of elongation between the seedlings grown under any two conditions of relative humidity indicated, in a soil either 20 per cent or 60 per cent saturated with water, are small. Comparing the seedlings grown in either soil moisture, the greatest difference in the rate of elongation, at a temperature of 20°C., occurred between those grown in a relative humidity of 60 per cent and those grown in a relative humidity of 90 per cent. With a soil 20 per cent saturated, the difference in the

12-hour increment between the plants referred to is 1.7± .40; in a soil 60 per cent saturated the difference is 1.3± .38. On referring to a table of odds, such as that given by Wood ('11) and Davis ('21), it may be found that the odds against such differences occurring under uniform conditions are 21 to 1 and 9.5 to 1, respectively. At a temperature of 30°C. these differences are less significant than are those at a temperature of 20°C., as the greatest difference gives odds of only 2 to 1. Before much dependence can be placed on a difference being significant, odds of at least 30 to 1 are demanded. Therefore, in the cases mentioned above, the odds are not sufficiently high to justify the placing of much reliance upon the seedlings, in the different groups, occupying the same position, relatively, if the experiments were repeated.

Table I. Mean 12-hour increments of elongation in shoots maintained at a temperature of 20°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean increment (in mm.)	Standard deviation	Coefficient of variability
5	30	10.8± .25	1.89± .18	17.5± 1.72
	60	12.5± .19	1.43± .13	11.5± 1.09
	90	13.3± .22	1.67± .15	12.6± 1.27
20	30	15.1± .19	1.42± .13	9.4± .86
	60	14.2± .24	1.86± .17	13.1± 1.22
	90	15.9± .33	2.42± .23	15.2± 1.48
60	30	15.0± .17	1.34± .12	9.0± .83
	60	14.7± .18	1.37± .13	9.4± .86
	90	16.0± .33	2.54± .23	15.9± 1.49

In the seedlings grown in a sand 5 per cent saturated, the situation is somewhat different. The differences between the mean increments of the seedlings grown in a relative humidity

of 30 per cent and the mean increments of the seedlings grown in a relative humidity of 60 per cent, at temperatures of 20° C. and 30°C., are 1.7± .32 and 3.3± .30, respectively. Between the means of the seedlings grown in a relative humidity of 60 per cent and the means of the seedlings grown in a relative humidity of 90 per cent, the differences are .8± .29 and .7± .30. In the former, the differences are significant, as the odds against the differences being due to pure chance are over 110 to 1 and several thousands to 1, respectively. In the latter, the differences are not significant, as the odds are less than 5 to 1.

Table II. Mean 12-hour increments of elongation in shoots maintained at a temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean increment (in mm.)	Standard deviation	Coefficient of variability
5	30	13.0± .19	1.44± .13	11.1± 1.02
	60	16.3± .23	1.80± .16	11.0± 1.01
	90	17.0± .19	1.38± .13	8.1± .77
20	30	19.9± .20	1.54± .14	7.7± .71
	60	20.3± .28	2.14± .20	10.5± .96
	90	20.0± .32	2.33± .23	11.6± 1.14
60	30	21.3± .42	3.17± .30	14.9± 1.58
	60	21.3± .23	1.78± .16	8.4± .77
	90	20.1± .39	2.77± .28	13.5± 1.37

A fact worthy of note in Tables I and II is that of the existence of a difference in the rate of growth between seedlings grown in soils of different water content. It may be observed that, at the three relative humidities employed and

at both temperatures, the differences in the rate of growth between the seedlings grown in a sand 20 per cent saturated and the seedlings grown in a sand 60 per cent saturated are small and without significance. Between the seedlings grown in a sand 5 per cent saturated and the seedlings grown in a sand 20 per cent saturated, however, marked differences are observable. In a relative humidity of 30 per cent, these differences are $4.3 \pm .32$ and $6.9 \pm .28$; in a relative humidity of 60 per cent, $1.7 \pm .30$ and $4.0 \pm .36$; and in a relative humidity of 90 per cent, $2.6 \pm .39$ and $3.0 \pm .37$. Referring to Wood's table of odds it may be found that the odds against such differences being due to chance, are in every case, upwards of 125 to 1 and in some cases reach many thousands to 1. Since the odds are well above 30 to 1, it is evident that these differences are sufficiently great to insure that relative humidity does exert an influence upon the rate of shoot elongation in seedlings growing in sand low in water content.

In respect to rate of elongation, the standard deviations, as given in Tables I and II, are only in certain cases good indices of variability. Since the value representing the coefficient of variability is dependent upon the relation between the mean increment and its standard deviation, the coefficient of variability expresses more accurately the range of variation. Table I brings out the fact that at a temperature of 20°C. the seedlings grown under the two extreme conditions,

in respect to moisture, possessed the greatest degree of variability. At a temperature of 30° C., the greatest degree of variability was exhibited by seedlings grown in a sand 60 per cent saturated.

Tables III and IV furnish the data supplying the mean fresh weights of the shoots of seedlings grown in temperatures of 20°C. and 30°C., respectively. The values indicate that, at both temperatures, there existed a close relation between the rates of elongation and the fresh weights of the shoots. The amount of water in the sand influenced, to a marked degree, the amount of material produced. These increases are the most striking in the rise from a soil moisture of 5 per cent saturation to one of 20 per cent saturation. Beginning with a relative humidity of 30 per cent and ending with a relative humidity of 90 per cent, the increases at a temperature of 20°C. are $.50 \pm .08$, $.36 \pm .07$ and $.81 \pm .05$. These differences are very significant, as in every case the odds against such differences being due to pure chance are upwards of 100 to 1. At a temperature of 30° C., the increases, in the same order, are $.64 \pm .066$, $.28 \pm .067$ and $.27 \pm .066$. In the first case, the chances that the seedlings in this group would occupy the same position, relatively, were the experiment repeated, are several thousands to 1; in the second case about 21 to 1; and in the third case about 20 to 1. Since the odds, in the last two, are below those generally accepted as the minimum for certainty, the significance of the differences are open to question.

In the rise from a soil moisture of 20 per cent saturation to one of 60 per cent saturation, the differences at both temperatures, are too small to be significant.

Table III. Mean fresh weights of shoots grown in an atmospheric temperature of 20°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean weight (in centigrams)	Standard deviation	Coefficient of variability
5	30	1.90± .05	.41± .04	21.3± 2.11
	60	2.04± .03	.26± .02	12.6± 1.20
	90	2.13± .05	.38± .03	17.6± 1180
20	30	2.40± .06	.45± .04	18.5± 1.75
	60	2.40± .06	.45± .04	18.6± 1.76
	90	2.94± .07	.54± .05	18.7± 1.82
60	30	2.62± .05	.40± .04	15.1± 1.41
	60	2.67± .07	.54± .05	20.2± 1.92
	90	3.16± .09	.67± .06	21.2± 2.02

Table IV. Mean fresh weights of shoots grown in an atmospheric temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean weight (in centigrams)	Standard deviation	Coefficient of variability
5	30	1.84± .043	.33± .030	17.9± 1.70
	60	2.11± .045	.35± .032	16.6± 1.56
	90	2.23± .043	.32± .031	14.3± 1.39
20	30	2.48± .05	.39± .036	15.7± 1.47
	60	2.39± .05	.39± .036	16.3± 1.54
	90	2.50± .05	.37± .036	14.8± 1.47
60	30	2.47± .05	.36± .034	14.6± 1.40
	60	2.57± .05	.37± .034	14.4± 1.35
	90	2.70± .07	.48± .048	17.8± 1.82

In Tables V and VI are presented the mean values of the dry weights of the shoots grown under the various conditions employed. If the data in Table V are examined, it may be found

that the differences between the means for the shoots in any two groups, grown under the same conditions of soil moisture, are insignificant. With but two exceptions are the differences less than their probable errors. At a temperature of 30°C. and in a soil 5 per cent saturated, a relative humidity of 90 per cent has given a much greater dry weight than has a relative humidity of 30 per cent. In this case, the difference is $2.4 \pm .54$. This gives odds of upwards of 30 to 1. In the same soil water content, the seedlings grown in a relative humidity of 60 per cent exhibited a greater dry weight than did those grown in a relative humidity of 30 per cent, but the difference is not great enough to rely on it occupying the same position, relatively, were the experiments repeated.

It may be observed that as the amount of soil water increases the dry weight of the shoot increases. The only marked differences, occurring at a temperature of 20°C., are found in passing from the seedlings grown in a soil 5 per cent saturated to those grown in a soil 20 per cent saturated. Even there the differences are too small to be of much significance. A significant increase in dry weight, brought about by an increase in soil moisture, is perceptible in the seedlings grown in a relative humidity of 30 per cent. When such seedlings grown in a soil 5 per cent saturated, are compared with those grown in a soil 60 per cent saturated, a difference of $2.6 \pm .54$ may be observed. This value furnishes odds of about 50 to 1 that the difference is due to environment and not to pure chance. At a temperature

of 30°C., the only significant difference (increase) in dry weight, brought about by an increase in the soil water, occurred also in seedlings grown in a relative humidity of 30 per cent. In this relative humidity, the means of the seedlings grown in a sand 20 per cent saturated exceeded the means of the seedlings grown in a sand 5 per cent saturated by 2.9± .55. This differ-

Table V. Mean dry weights of shoots grown in an atmospheric temperature of 20 C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability	Per cent of green wt.
5	30	14.0± .43	3.22± .31	23.0± 2.30	7.3
	60	14.9± .30	2.29± .21	15.4± 1.47	7.3
	90	15.4± .46	3.31± .32	21.5± 2.22	7.2
20	30	16.0± .56	4.21± .40	26.3± 2.55	6.7
	60	15.7± .45	3.50± .32	22.3± 2.15	6.6
	90	16.4± .32	2.37± .23	14.6± 1.42	5.6
60	30	16.6± .32	2.43± .22	14.6± 1.37	6.3
	60	17.0± .49	3.78± .35	22.2± 2.27	6.3
	90	16.6± .42	3.26± .30	19.6± 1.87	5.3

ence, according to Wood, furnishes odds of about 100 to 1 that a similar difference would occur again under the same conditions of experimentation.

On further examination of Tables V and VI, it may be observed that a constant relation between the mean fresh weights and the mean dry weights of the shoots of seedlings, subjected to different environmental conditions, does not exist. As the percentage of soil moisture was increased, the water content of the resulting shoots became higher. This appears to be constant under the prevailing experimental conditions. A fact worthy

of note in this connection is the occurring of a difference in the part played by the soil water and atmospheric moisture at the two temperatures employed. At a temperature of 20°C., relative humidity exerted no influence on the per cent of dry matter present in the shoots of seedlings growing in a sand 5 per cent saturated. At a temperature of 30°C., with the same per cent of soil water, this did not hold. In seedlings grown at a temperature of 20°C. and in soil moistures of 20 per cent and 60 per cent saturation, relative humidity influenced, to a marked degree, the per cent of dry matter present; while in seedlings grown at a temperature of 30°C. and in the same soil moistures, differences in the relative humidity brought about only slight changes in the per cent of dry matter present.

Table VI. Mean dry weights of shoots grown in an atmospheric temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability	Per cent of green wt.
5	30	14.9 ± .41	3.2 ± .29	21.5 ± 2.07	8.1
	60	16.5 ± .38	2.9 ± .27	17.6 ± 1.67	7.8
	90	17.3 ± .35	2.6 ± .25	15.0 ± 1.46	7.3
20	30	17.8 ± .37	2.9 ± .26	16.3 ± 1.53	7.2
	60	17.4 ± .42	3.2 ± .29	18.4 ± 1.74	7.3
	90	16.7 ± .41	3.0 ± .29	18.0 ± 1.80	6.7
60	30	16.9 ± .34	2.6 ± .24	15.4 ± 1.53	6.8
	60	17.3 ± .32	2.5 ± .23	14.4 ± 1.35	6.7
	90	18.0 ± .54	3.8 ± .37	21.1 ± 2.18	6.7

Tables VII and VIII bring out the relative values of different combinations of soil moistures and relative humidities in the production of dry weight in roots of seedlings. In the

seedlings grown at a temperature of 20°C., a condition opposite to that occurring in shoots may be observed. In roots the greatest dry weights occurred in seedlings grown in a soil 5 per cent saturated and in a relative humidity of 30 per cent, while in shoots the lowest dry weight occurred under these same conditions. The only consistent differences in the mean dry weights in the roots of seedlings, grown at this temperature and grown under the same conditions of soil moisture, occurred where a soil 5 per cent saturated was employed. But even there, the value by which the seedlings grown in the lowest relative humidity exceed the seedlings grown in the highest relative humidity gives odds against the difference being due to chance of less than 20 to 1. In the seedlings grown at an atmospheric temperature of 30°C., the maximum dry weight occurred under conditions of medium soil moisture. The differences in either direction are too small to be of much significance.

Table VII. Mean dry weights of roots of seedlings the shoots of which were maintained at a temperature of 20°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability
5	30	4.7± .15	1.09± .10	23.2± 2.32
	60	4.4± .10	.72± .07	16.4± 1.58
	90	3.9± .13	.92± .09	23.6± 2.40
20	30	4.3± .12	.95± .09	22.1± 2.13
	60	4.0± .11	.96± .08	24.0± 2.33
	90	4.2± .12	.89± .08	21.2± 2.11
60	30	4.0± .09	.71± .06	17.7± 1.68
	60	4.1± .12	.97± .09	23.7± 2.28
	90	3.8± .09	.71± .06	18.7± 1.76

Table VIII. Mean dry weights of roots of seedlings, the shoots of which were maintained at a temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability
5	30	3.9 ± .14	1.10 ± .10	28.2 ± 2.78
	60	3.8 ± .10	.74 ± .07	19.5 ± 1.85
	90	4.2 ± .05	.36 ± .03	8.6 ± .83
20	30	4.2 ± .11	.83 ± .08	19.8 ± 1.88
	60	4.1 ± .08	.63 ± .06	15.4 ± 1.45
	90	4.2 ± .07	.49 ± .05	11.7 ± 1.16
60	30	3.9 ± .07	.54 ± .05	13.8 ± 1.32
	60	3.6 ± .06	.45 ± .04	12.5 ± 1.17
	90	3.7 ± .10	.71 ± .07	19.2 ± 1.97

Table IX. Mean weights of seeds from which the seedlings grown at 20°C. were obtained.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability
5	30	44.0 ± 1.09	8.09 ± .77	18.3 ± 1.80
	60	43.0 ± .66	5.07 ± .47	11.8 ± 1.13
	90	46.0 ± 1.01	7.77 ± .71	16.9 ± 1.73
20	30	47.6 ± .97	7.30 ± .68	15.3 ± 1.47
	60	46.7 ± 1.07	8.25 ± .76	17.7 ± 1.67
	90	47.0 ± .70	5.20 ± .49	11.1 ± 1.08
60	30	44.3 ± .78	6.03 ± .55	13.6 ± 1.27
	60	47.0 ± 1102	7.82 ± .72	16.6 ± 1.55
	90	46.6 ± .94	7.61 ± .66	16.3 ± 1.53

On examination of Tables IX and X it may be observed that the differences occurring between any two means in seed weights are small. The greatest differences in mean weights of seeds, from which the seedlings grown under the different environments were obtained, amounts to 7 ± 1.6 and 4 ± 1.3. In both cases the differences give odds of less than 25 to 1. Since

these odds are rather small to be significant, the differences in the rates of elongation cannot be accounted for through differences in the weights of the seeds employed.

Table X. Mean weights of seeds from which the seedlings grown at 30°C. were obtained.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability
5	30	42± 1.3	9.7± .90	23.1± 2.22
	60	45± .96	7.4± .68	16.4± 1.55
	90	47± .69	5.3± .49	11.3± 1.09
20	30	49± .96	7.4± .68	15.1± 1.42
	60	46± .96	7.4± .68	16.1± 1.52
	90	45± .84	6.1± .59	13.6± 1.34
60	30	45± .78	5.9± .55	13.1± 1.25
	60	44± .83	6.4± .59	14.5± 1.36
	90	47± 1.21	8.6± .85	18.2± 1.87

Tables XI and XII furnish the mean total increments of elongation in the shoots of seedlings grown under the different conditions of temperature, soil moisture and relative humidity employed. On examination of the tables it may be found that, with but one exception, the seedlings grown in a soil moisture of 5 per cent saturation made smaller total increments than those grown in the higher soil moistures. The differences in every case, excepting the one referred to, are significant. Between the seedlings grown in a soil moisture of 20 per cent and those grown in a soil moisture of 60 per cent saturation, the only significant differences may be found in those grown at a temperature of 20 C. and in a relative humidity of 60 per cent. In this instance, the difference is 59± 6.76.

Differences brought about by relative humidity occur in a few cases. In Table XI, it may be observed that in a soil moisture of 20 per cent saturation the seedlings grown in a relative humidity of 60 per cent made an increment significantly smaller than those grown in relative humidities of either 30 per cent or 90 per cent. In the same table, but in a soil 60 per cent saturated, the seedlings grown in a relative humidity of 60 per cent exceeded those grown in a relative humidity of 30 per cent by 42 ± 7.82. In this case, the odds that the difference is not due to pure chance are about 100 to 1. In Table XII a significant increase brought about by an increase in the relative humidity may be found in the seedlings grown in a soil moisture of 5 per cent saturation. The difference referred to occurs between those grown in relative humidities of 30 per cent and 60 per cent,

Table XI. Mean total increments of elongation in shoots maintained at a temperature of 20° C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean increment (in mm.)	Standard deviation	Coefficient of variability
5	30	247 ± 2.70	20.0 ± 1.91	8.1 ± .77
	60	262 ± 3.40	25.7 ± 2.40	9.8 ± .92
	90	231 ± 6.96	53.6 ± 4.93	23.2 ± 2.42
20	30	301 ± 4.39	33.2 ± 3.12	11.0 ± 1.03
	60	257 ± 5.61	43.1 ± 3.96	16.8 ± 1.58
	90	308 ± 5.61	41.6 ± 3.96	13.5 ± 1.31
60	30	274 ± 6.85	52.7 ± 4.85	19.2 ± 1.83
	60	316 ± 3.78	29.1 ± 2.66	9.2 ± .84
	90	306 ± 5.50	42.3 ± 3.89	13.8 ± 1.29

respectively. The odds in this case, according to Wood ('11), approach 1000 to 1.

Table XII. Mean total increments of elongation in shoots maintained in a temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean increment (in mm.)	Standard deviation	Coefficient of variability
5	30	233± 4.28	32.9± 3.02	14.1± 1.32
	60	274± 4.40	33.8± 3.10	12.3± 1.15
	90	256± 3.68	27.3± 2.60	10.7± 1.04
20	30	315± 3.55	27.4± 2.51	8.7± .79
	60	306± 4.13	31.8± 2.92	10.4± .96
	90	288± 6.22	45.2± 4.40	15.7± 1.56
60	30	320± 3.88	29.3± 2.74	9.1± .85
	60	300± 3.92	30.2± 2.77	10.1± .93
	90	314± 4.70	33.4± 3.32	10.6± 1.06

Mention may here be made of the general character of the root systems found on the seedlings grown in silica sand of different moisture contents. No actual dataare available, but striking differences in the length and the extent of the branching in the root systems were observed. Seedlings grown in a sand 5 per cent saturated possessed a short main root with many laterals. Those grown in a sand 60 per cent saturated possessed a long main root with few laterals. Those grown in a sand 20 per cent saturated possessed roots occupying a position, in respect to character, intermediate between the other two. In the seedlings of the last group, the main roots were moderately long and the lateral roots more numerous than in those grown in a sand 60 per cent saturated.

2.. Growth of Seedlings in Darkness Alternating with Light.

The data presented in Tables XIII and XIV give the

increments of elongation and the total fresh weights in bean seedlings that were subjected to a daily illumination of 12 hours. On inspection of the data it may be found that the mean 12-hour increments are the same. In respect to fresh weight, the value for the seedlings grown in a relative humidity of 90 per cent is the higher, but it exceeds the value for the seedlings grown in a relative humidity of 30 per cent by only $.09 \pm .063$. It is evident that this difference is too small to be significant. From the data presented in these tables it appears that, under the conditions of the experiment in question, a low relative humidity is as favorable as a high relative humidity in the formation of fresh material in shoots of bean seedlings.

Table XIII. Mean 12-hour increments of elongation in shoots maintained in a temperature of 30° C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean increments (in mm.)	Standard deviation	Coefficient of variability
20	30	$17.2 \pm .19$	$1.44 \pm .13$	$8.4 \pm .77$
	90	$17.2 \pm .29$	$2.14 \pm .20$	12.4 ± 1.20

Table XIV. Mean fresh weight of shoots maintained in a temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean weights (in grams)	Standard deviation	Coefficient of variability
20	30	$2.15 \pm .041$	$.32 \pm .029$	14.9 ± 1.40
	90	$2.24 \pm .050$	$.37 \pm .035$	16.6 ± 1.62

On comparing the values in these tables with the corresponding values for the seedlings grown in continuous darkness, significant differences are found. In the rate of

elongation, the seedlings grown in continuous darkness exceeded those grown in part time illumination by values that give odds of upwards of 1000 to 1 that the differences are not due to pure chance. In respect to fresh weight, the only difference giving odds above 30 to 1 occurs in the seedlings grown in a relative humidity of 30 per cent.

Table XV. Mean total increments of elongation in shoots maintained in a temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean increment (in mm.)	Standard deviation	Coefficient of variability
20	30	219 ± 2.41	18.5 ± 1.70	8.4 ± .77
	90	241 ± 3.50	25.9 ± 2.48	10.7 ± 1.03

In Table XV the difference in the mean total increments of elongation in the illuminated shoots is shown. The difference occurring is 22 ± 4.25. Considering the probable error, this furnishes odds of about 75 to 1 that the difference is not due to pure chance. Since these odds are above the minimum accepted for certainty, this difference may be considered significant.

The total increments of elongation, as given in Table XV, are decidedly smaller than the corresponding ones in Table XII. In the two relative humidities (30 per cent and 90 per cent) the differences occurring are 100 ± 4.23 and 47 ± 7.14, respectively. In the former case, the odds that the difference is not due to chance are upwards of 1,000,000 to 1; in the latter case, upwards of 500 to 1. These odds are sufficiently great to be significant.

Table XVI brings out the difference in the dry weight of shoots subjected to relative humidities of 30 per cent and 90 per cent, respectively. The difference occurring is 3.0± .70. While this difference appears great enough to be significant, odds of only 22 to 1, that each would occupy the same relative position upon repeating the experiment, are found when due consideration is given the probable error. If we are to accept odds of 30 to 1 as our measure of certainty, little reliance can be placed on the above difference being due to a difference in the relative humidity. It may be observed that a wide difference occurs between the values representing the degree of variability. The difference, though 14.6± 3.72, is too small to be significant, as the odds are less than 20 to 1. On further examination of the table, a difference in the per cent of dry material produced, in the respective relative humidities, may be observed. While similar to that occurring in the etiolated seedlings this difference is much more striking.

Table XVI. Mean dry weights of shoots grown in an atmospheric temperature of 30° C.

Soil moisture (per cent saturation)	R. humidity (percent)	Mean wt. (in cg.)	Standard deviation	Coefficient of variability	Per cent of green wt.
20	30	16.8± .38	2.9± .27	17.3± 1.64	7.8
	90	13.8± .59	4.4± .42	31.9± 3.34	6.2

The difference between the dry weights in roots of seedlings, as brought out in Table XVII, is not striking. Although the difference is .3± .13, the probable error is of such

magnitude that but little reliance can be placed upon their holding the same position, if the experiment were repeated. It may be observed, however, although the differences are not great enough to be significant, that the relation of shoot and root to moisture supply appear to be the same in the seedlings grown in part time illumination as in the seedlings grown in continuous darkness.

Table XVII. Mean dry weights of roots of seedlings the shoots of which were maintained in a temperature of 30°C.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean weight (in cg.)	Standard deviation	Coefficient of variability
20	30	4.2 ± .088	.68 ± .062	16.2 ± 1.54
	90	3.9 ± .084	.62 ± .059	15.9 ± 1.55

As in the case of the etiolated seedlings, the difference between the mean weights of the seeds, from which the two groups of illuminated seedlings were grown, is small. The difference, as indicated in Table XVIII, is only 2 ± 1.27. Little assurance is afforded that the same ofder of values would hold upon repeating the experiment.

Table XVIII. Mean weights of seeds from which the seedlings grown at 30 C. were obtained.

Soil moisture (per cent saturation)	R. humidity (per cent)	Mean weight (in cg.)	Standard deviation	Coefficient of variability
20	30	45 ± .95	7.3 ± .67	16.2 ± 1.53
	90	43 ± .85	6.3 ± .60	14.6 ± 1.42

In respect to mean dry weights of shoots, mean dry weights of roots and mean weights of seeds, significant differ-

ences between the values given in Tables XVI, XVII and XVIII and the corresponding values in Tables VI, VIII and X do not appear.

The seedlings grown in darkness alternating with light differed in their characters from those grown in continuous darkness. One of the chief differences occurred in leaf development. The leaves of the seedlings maintained in darkness remained small and in many cases did not unfold. The leaves of the seedlings grown in darkness alternated with light unfolded early, and at the conclusion of the experiment had attained a size several times that of the leaves in the etiolated seedlings. Another important difference between these two groups of seedlings was in color. The seedlings grown in darkness alternated with light developed a deep green color, while those grown in continuous darkness remained pale yellow. This greening in the seedlings illuminated part time could be observed soon after their exposure to light, and at the end of the first day the primary leaves exhibited the color characterizing normal, illuminated plants.

In addition to the data presented in the previous tables, data were obtained on the amounts of water given off by the seedlings during the period of observation. In the present paper these data have been omitted, owing to plans to present them in a separate paper in the near future.

The results of our experiments briefly summarized show: (1) that only in a soil 5 per cent saturated is there a significant increase in the rate of elongation brought about by

an increase in the relative humidity; (2) that as the soil water is increased from 5 per cent saturation to 20 per cent saturation a significant increase in the rate of elongation in etiolated shoots occurs; (3) that, in general, the higher the moisture supply, either in the atmosphere or in the soil, the lower is the per cent of dry matter in the plant; (4) that changes in the amount of soil water from 5 per cent to 60 per cent saturation do not bring about significant changes in the relation between the dry weights of root and shoot; (5) that light retards growth.

VII. DISCUSSION.

Already, attention has been called to the fact that the results obtained on growth in relation to relative humidity, in this investigation, do not accord with the results obtained in some of the previous investigations. The data furnished by these other investigators do not allow of an explanation of the discrepancies. If an exact knowledge of the conditions under which these investigators worked were known, it is probable that these differences, in part at least, could be accounted for. It is true that plants of all species do not agree in their response to every environmental condition. It is possible that plants of one species may react more favorably to a high relative humidity than to a low one and that plants of another species, under the same conditions of environment, may react more favorably to a low relative humidity than to a high one.

A definite answer to this question, however, awaits future investigation. Imperfect control of the environmental conditions in the previous investigations are responsible, in a large measure, for the differences obtained. In some cases contributing environmental factors have been entirely overlooked and the data presented were obtained from plants or seedlings grown under conditions widely different from those indicated.

In previous researches on growth in relation to environmental conditions, with but few exceptions the cultures under observation have comprised but small numbers of individuals. In only a few cases has the number exceeded ten and in many cases the number employed has been less than five. It has been pointed out by recent workers that conclusions based on such small samples may be entirely erroneous. It is known that plants of the same species, under the same conditions of environment, show wide variations in the rate of elongation. The plants or seedlings exhibiting the highest growth rate, among those in an unfavorable environment, may make more rapid growth than the plants or seedlings exhibiting the lowest growth rate among those in a favorable environment. If, in comparing two environments in respect to their effect upon growth, the plants selected should fall in the classes referred to, it is obvious that the conclusions drawn would be misleading. Thus, it may be seen that conclusions drawn from few individuals or from few cultures may lead to grave error. Considering the great complexity in the factors conditioning the results, and the absence

of full appreciation of these, lack of consistency in the conclusions reached by earlier investigators is to be expected.

The results of Sorauer ('80), Reinitzer ('81), Reinke ('76), Wollny ('98), Anderson ('94), Darwin ('93), Clark ('78), Tsclaplowitz ('86) and Eberhardt ('03) apparently agree, only in part, with the results obtained in the present investigation. While some of these investigators secured very marked advantages in favor of the higher relative humidities, others secured only a slight balance in that direction. A definite explanation for these differences in growth cannot be given. It has been stated already that there is a possibility of plants of different species responding differently to a given set of conditions. By some it may be suggested that the great diversity of plants employed, in the experiments referred to, will account for the discrepancies. There is, however, no experimental evidence to lend support to such a view. The small differences shown in the tables presented by some of these investigators are no greater than the differences which, in this discussion, have been considered insignificant. In addition, the number of cultures employed in the present investigation greatly exceeds the number employed in any of the investigations referred to. In fact, in some cases the conclusions reached by former investigators were based upon the growth of a single individual. This renders their differences less significant than if larger numbers had been employed. Owing to the use of such small numbers, it

may be that the differences obtained are only chance differences and that, if the experiments were repeated, the lower relative humidity would be equally as favorable to growth as the higher relative humidity.

On the other hand, the results obtained by Schaible ('01) agree with the results obtained, in the present investigation, on seedlings grown in a sand high in water content. If Vesque and Viet ('81) had based their conclusions upon the average growth of all individuals grown, rather than upon the best individual from each group, their conclusions would have agreed very well with those of Schaible.

Since the dry air admitted to the plant chambers was not controlled, in the investigations mentioned, it is not unlikely that in some cases the relative humidity reached a value much lower than the lowest employed in the present investigation. Where very marked differences in the growth rate between seedlings grown in a dry atmosphere and seedlings grown in a moist atmosphere occurred, as in the investigations of Reinitzer ('81), the air on entering the plant chamber was passed through tubes containing pumice stone moistened with sulphuric acid. Under such conditions, the relative humidity of the air entering the plant chamber undoubtedly reached a value below 30 per cent. This very low relative humidity, possibly combined with unfavorable conditions of soil moisture, may assist in accounting for the wide differences in the growth rates recorded.

The data presented in the previous section of this paper bring out the fact that in a study of growth in relation to relative humidity soil moisture must be considered. In these experiments, a silica sand 20 per cent saturated has proved to be capable of supplying water to seedlings, growing in a relative humidity of 30 per cent, as rapidly as required for maximum growth. This confirms the conclusions reached by Hellriegel ('83) who recognized that the amount of water given off by the plant exerted no retarding influence upon the growth rate, so long as the amount of water in the soil was maintained within favorable limits. The observation of Hellriegel ('69), Fittbogen ('73), Sorauer ('73), Wollny ('88, '92, '97), Gain ('92, '95, '96), Shroeder ('96), Mayer ('98), Tucker and Seelhorst ('98), Pagnoul ('99), Seelhorst ('00), Prianishnikov ('00), Seelhorst and Freckmann ('03), Bunger ('06), Preul ('08), Harris ('14), Kiesselbach ('15), Shive ('20) and others are not at variance with this view. Although the above investigators make no mention of relative humidity in their investigations, evidence is presented in favor of the view that soil moisture is a very important factor in determining growth rate in plants. Burkholder ('19) has shown that plants of the common bean, affected by the dry root-rot, are able to carry on their normal functions if an abundance of water is present in the soil. If, however, the soil moisture decreases, the few remaining roots are unable to supply the plant with the requisite amount of water and the growth rate decreases accordingly. The data presented in this

paper show that in a sand only 5 per cent saturated the available water is not present in sufficient amounts to supply the needs of the plant for maximum growth. Under such conditions of soil moisture, a higher growth rate would be expected in the presence of a high relative humidity than in the presence of a low relative humidity. This occurred in the present investigation. From these considerations it seems probable that soil moisture was a limiting factor (Blackman, '05) in at least some of the investigations referred to.

The observations of Kraus ('95), Lock ('04) and Smith ('06), agree with those of Reinitzer ('81). Smith ('06) and Lock ('04) attributed to relative humidity a great rôle in determining the growth rate in shoots of Dendrocalamus. This may have been warranted, but the data on growth in bean seedlings presented in this paper show that in doing so soil moisture must receive due consideration. The evidence brought forth in Table I suggests that the relation between relative humidity and plant growth is more complex than these authors have indicated. This complexity in the environmental relations of plants growing in nature is further brought out by the observations of Douglas ('06), Greeley ('20), Maxwell ('96), Prantl ('73), Stebler ('78) and others.

That relative humidity, as a factor influencing the growth rate, has been greatly overestimated and that soil moisture, in this respect, has been greatly underestimated is supported

by the conclusions reached by Shibata. A curve representing the growth rate in shoots of Dendrocalamus, as observed by him, shows no relation to the corresponding curve for relative humidity. While the relative humidity, at times, reached a low value, the water required was present in the soil in sufficient amounts to supply the needs of the plants, without inducing a depression in the growth rate.

The relation of growth rate to soil moisture, as shown in Tables I and II, confirms the conclusions reached by Pearson ('18), Douglas ('09, '14), Kelsick ('18), Kirkwood ('14), Bogue ('05), and Taylor and Downing ('17). Pearson states, "The important fact pointed out by this study, however, is that it is the April and May precipitation which is most important in determining the amount of height growth and presumably the moisture content of the soil during the period when height growth takes place". Similar conclusions were reached by the remaining authors.

With respect to the effect of soil moisture upon the weight of material produced in root and in shoot, the results given in Tables III - VIII and XV - XVII in this paper agree only in part with those of Hellriegel ('69), Sorauer ('73), Gain ('92, '95, '96), Shroeder ('96), Mayer ('98), Wollny ('98), Tucker and Seelhorst ('98), Pagnoul ('00), Seelhorst and Freckmann ('03), Bunger ('06), Preul ('08), Seelhorst and Kizymowski ('10) and Shive ('20). The above authors seem to agree in having observed that from an increase in the soil moisture, increases in the fresh and dry weights of the shoot and a decrease

in the dry weight of the root result. Tucker and Seelhorst ('98) state "Die Ausbildung der oberirdischen Pflanzensubstanz der Haferpflanze nahm mit steigendem Wassergehalt zu; bei den Wurzeln war das Umgekehrte der Fall. Bei einem geringen Wassergehalt des Bodens trat die relativ grösste Ausbildung der Wurzeln die relative geringste der oberirdischen Masse ein". Their data indicate increases in the weight of plant substance with increases in the soil moisture, until the soil reaches a point where it is from 60 per cent to 90 per cent saturated. Omitting the probable error, the data furnished in the tables referred to confirm, in a general way, the results obtained by these authors. However, when consideration is given this error, these data indicate no significant increases in the weights of the plants, beyond a soil moisture of 20 per cent saturation. It must not be forgotten that in the investigations already referred to, the plants were grown for a longer period than were those in the present investigation. The wide difference in the stage of development at the time of analysis may account for the discrepancies noted. The absence of light in the plant chambers employed, as indicated, and differences in temperature and relative humidity may be important factors for consideration in this connection. A similar explanation to that of the former may be suggested for the results obtained by Polle ('10) on seedlings of wheat and barley, which agree with those obtained in the present investigation.

With respect to the relation between fresh and dry

weights in shoots of seedlings grown under different conditions of moisture, the results presented in Tables V, VI and XVI ~~that~~ accord with the results obtained by previous investigators. Sorauer ('81), Gain ('95), Wollny ('98), Pagnoul ('99) and Prianishnikov ('00) observed that as the per cent of water in the soil was increased the per cent of dry matter in the plants decreased. Their results, as reported, are consistent and in some cases marked differences were obtained. Some slight inconsistencies are shown in Tables V and VI, but on the whole a distinct relation between the amount of water present in the soil or in the atmosphere and the per cent of dry matter present in the plant exists. The difference is more striking in the seedlings grown under part time illumination than in the seedlings grown in continuous darkness. The observations on the illuminated seedlings agree more closely, as would be expected, with the observations of the investigators mentioned. The higher percentage of dry matter occurring in the seedlings grown under the less favorable moisture conditions are due, undoubtedly, to a greater development of strengthening tissue, as demonstrated by Kohl('86) and Wollny ('98).

It has been shown that soil moisture and relative humidity play a part in determining the total increment of elongation in plant shoots. The data presented in Tables XI and XII indicate that a soil very low in moisture provides less favorable conditions for longitudinal growth in plant shoots than a soil

high in moisture. The single exception to this has already been noted. With this one exception, the increases in the total increments occurring in soil moistures of 20 per cent saturation and 60 per cent saturation, as shown in Tables XI and XII, are not unlike those obtained by Sorauer ('73), Hellriegel ('83), Gain ('92), Wollny ('97), Seelhorst ('00), Bunger ('06) and others. Their results differ from those presented in the tables referred to, however, in that increases in total elongation were obtained in soil moistures much above 20 per cent saturation. It is true that in the present investigation soil moistures between 20 per cent and 60 per cent saturation were not employed. It is, possible, therefore, that a soil moisture, intermediate between these two, would provide more favorable conditions for elongation in shoots than those employed. A definite answer to this awaits further investigation. The fact that in the researches referred to the plants were grown in light, while the seedlings furnishing the data presented in the tables indicated were grown in darkness, may account for this discrepancy.

With reference to the exception noted above close inspection of the tables suggests that this value does not truly represent the total increment for the seedlings falling in that group. This wide difference is due possibly to chance. If this experiment were repeated fifty or a hundred times, it is probable that in every case the value would approach more nearly

the values of the seedlings in the neighboring groups.

In respect to the effect of relative humidity on the total length of shoots, the researches of Reinitzer ('81), Wollny ('98), Eberhardt ('03, '04) and others are confirmed by certain of the data presented in this paper. The number of cases in which relative humidity has brought about a significant difference in the total increment of elongation, however, is too small to place much reliance on relative humidity, within the limits of that commonly occurring in nature, being an important factor in determining the total length of plant shoots.

In presenting the data, attention was called to the differences in the rate of elongation between the seedlings grown in darkness and those grown in part time illumination. As already indicated, the differences are very significant. Light decreased not only the rate of growth, but also the total increment of growth made during the period of observation. This agrees with the conclusions reached by Prantl ('73), Sachs ('74), Stebler ('78), Barenetsky ('79), Godlewski ('91) and others. On the other hand, the observations of Meyer ('28), Maxwell ('96), Vogt ('15) and others do not accord with the results reported in this paper. In seedlings of sunflower, growing in the free air, Reinke ('76) observed that growth took place more rapidly by night than by day. Where relative humidity was maintained constant, however, he observed a more rapid growh in light than in darkness. It is difficult to account for the

wide differences in the results obtained by the various investigators. Mention may be made of the fact that Reinke based his conclusions upon the results obtained from one or two plants. The uncertainties in drawing conclusions from few individuals have already been pointed out, and it is probable that some of the discrepancies may be accounted for through differences in the number of cultures employed. In some cases, the differences obtained between plants growing in light and plants growing in darkness were ascribed to the presence of light or to the absence of light, while other factors were disregarded. Under such circumstances lack of consistency in the results obtained may be expected. However, the evidence brought forth in this paper that light has a retarding effect upon growth should stimulate further investigation in this field.

The observations in this investigation on the character of the root systems found on seedlings growing in soils of different moisture content do not agree with those of Gain ('95). This author states, "L'humidité du sol parait ralenter la croissance terminale de la racine principale, et exagérer la croissance des ramifications secondaires et tertiaires. Ces résultats sont inverses de ceux qui on observe sur la tige." Gain based this statement upon observations made on plants of buckwheat. Observations on seedlings grown in this laboratory indicate that, under a given set of conditions, plants differ in respect to the type of root system produced. This may account for the

differences obtained. It is probable also that differences in the nature of the soil will prove an important factor for consideration in accounting for this discrepancy.

Aside from their importance to the botanist, the results obtained in this investigation give promise of much worth to the agriculturist. Definite values from the agriculturist's viewpoint cannot be assigned to them, however, until further researches are made. In assigning to them a value it must not be overlooked that this investigation was confined to a study of plants of the common bean in the seedling stage. Giving this due consideration, the results already obtained are suggestive and give some indication of what may be expected from plants in the more advanced stages of growth.

If plants of other species, growing under natural conditions, prove to respond to moisture in a manner similar to that of seedlings of the common bean, the results obtained in this investigation will have wide application. If these results apply universally, relative humidity and the evaporating power of the air may, in a large measure, be disregarded. The moisture of the soil, on the other hand, must receive greater attention. In the irrigated districts the relative humidity is low, and little may be done toward increasing it. The water of the soil, on the other hand, may be increased readily and any desired per cent of saturation obtained. In districts where irrigation is not practiced and where the supply of soil moisture depends largely upon the precipitation, greater attention

to the conservation of that moisture may be given. Briggs and Shantz ('13, '14) have shown that farm crops, producing an average yield, require from 6 to 18 acre inches of water for the completion of growth. Except in arid regions the annual precipitation greatly exceeds that required for the production of a crop. By employing the most improved methods of cultivation, the loss of moisture from the soil may be reduced to a minimum and the conditions for plant growth thereby improved. In the greenhouse, except in special cases, the relative humidity of the atmosphere may receive less attention, while more attention is given to soil water. Through a more favorable supply of soil moisture the harmful effects of high rates of evaporation and transpiration, brought about by low relative humidities and warm winds may, in a measure, be overcome.

VIII. SUMMARY.

1. Elongation in etiolated shoots of seedlings of the common bean, growing in a pure silica sand either 20 per cent or 60 per cent saturated with water, proceeded as rapidly in a relative humidity of 30 per cent as in a relative humidity of either 60 per cent or 90 per cent.

2. The shoots of etiolated bean seedlings growing in a pure silica sand 5 per cent saturated elongated less rapid-

ly in a relative humidity of 30 per cent than in relative humidities of 60 per cent and 90 per cent.

3. In a pure silica sand 5 per cent saturated, the shoots of etiolated bean seedlings elongated as rapidly in a relative humidity of 60 per cent as in a relative humidity of 90 per cent.

4. The rate of elongation in shoots of bean seedlings growing in darkness alternating with light appears to be influenced by relative humidity in a manner not unlike that in shoots of similar seedlings growing in continuous darkness.

5. The shoots of bean seedlings growing in darkness alternating with light elongate less rapidly than the shoots of similar seedlings growing in continuous darkness.

6. In the presence of both high and low relative humidities, etiolated bean seedlings elongate more rapidly in a silica sand 20 per cent saturated with water than in a silica sand 5 per cent saturated with water. In a sand 60 per cent saturated, the rate of elongation approaches that in a sand 20 per cent saturated.

7. The per cent of dry matter in the plant varies inversely as the soil moisture and the relative humidity.

8. Significant changes in the relation between the dry weights of roots and the dry weights of shoots were not brought about by increasing the soil water from 5 per cent saturation to 60 per cent saturation.

IX. CONCLUSIONS.

1. The influence of relative humidity upon growth in higher plants has been greatly overestimated.

2. In studies on growth in relation to relative humidity, the available moisture in the substratum must be recognized as an important environmental factor.

3. The harmful effects of low relative humidity and atmospheres possessing high evaporating coefficients upon growth in plants, may be overcome, in a large measure, by maintaining an abundance of moisture in the substratum.

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